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   Patents ADP number *(if you know it)* — 8183857001

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4. Title of the invention

   IMPROVEMENTS RELATING TO ELECTRONIC CIRCUIT PACKAGES

5. Name of your agent *(if you have one)* — CLARKE ALAN

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Improvements Relating to Electronic Circuit Packages

This invention relates to the field of electrical circuit packages, and more specifically to packages for circuits designed to operate at radio frequency, microwave or millimetre wave frequencies. For the purposes of this specification such frequencies will be referred collectively as high frequencies.

Electrical circuits operating at high frequencies will, due to their nature, often radiate electromagnetic (EM) energy. Such radiation is often unwanted, and can cause problems if the radiation couples into nearby components or circuit board tracks etc, and can lead to unpredictable or unwanted circuit behaviour. For this reason, particularly sensitive parts of a circuit, or those components that are particularly prone to radiate, are frequently packaged in metal or otherwise electrically conductive packages, with the package held at a fixed potential. This can reduce the coupling between circuitry mounted in separate packages, and so alleviate the problem. However, this can sometimes lead to an increased EM coupling within an individual metallic package, leading to a particular sub-circuit mounted within a package to couple back to itself.

The problem gets worse as the frequency of operation gets higher, as the EM radiation wavelength will get correspondingly shorter, and hence be closer to a length at which the package itself will be resonant. Resonances can cause strong enhancements in field strengths, and this will tend to result in increased coupling between components, or circuit board tracks, and even between different elements of the same component within the package, which can lead to undesired circuit behaviour generally, and even oscillation if active circuits are involved.

A known solution is to coat the top and/or sides of the package with radiation absorbent material (RAM), or place blocks of RAM into the cavity. RAM is a material having the property that it tends not to reflect incident EM radiation, or allow all the radiation to pass through it. Instead, it is designed to absorb the radiation, effectively dissipating the energy as heat. Some types of these materials are quite thick, as to be effective they need to match the impedance

of the radiated wave to the resistance of a dissipative material within the RAM. These are awkward to use in high frequency packages, particularly at the millimetre wave frequencies, due to the size of package required to accommodate the RAM, and the need to fabricate materials with the necessary material parameters.

Other types of RAM are much thinner. Emerson & Cuming Microwave Components manufacture a variety of sheet materials able to act as RAM. The thinnest of these relies upon wavelength dependent effects, and so is inherently narrow band. Other types have a specific resistance that is graded throughout the material thickness to reduce reflections from the surface. These work over a broader bandwidth, but also tend to be thicker. When used in a cavity in which electronic components are mounted the absorption efficiency of these materials all tends to reduce as the frequency of operation of the circuitry increases. This has been verified by measurements performed by the inventor.

US patent 6,054,766 discloses an electrical circuit package designed to address some of the problems described above. The package disclosed is made in whole or in part of silicon sheets, the sheets having a stated specific conductivity σ of between 1 and 10 $\Omega^{-1}m^{-1}$. Traditionally, packages for high frequency circuits are often made from a solid piece of aluminium, with cavities milled out to hold the circuits themselves. Thus the disclosure of US6,054,766 will thus require the traditional packages to be abandoned, or, at best, modified so as to enable the silicon sheeting to be used as described therein.

According to the present invention there is provided a package for a high frequency electrical circuit comprising a cavity formed within a material for containment of the electrical circuit, characterised in that the package contains at least one vane positioned on an inner surface of the package such that the or each vane substantially extends into the cavity, the or each vane at least partly comprising a conductive material.

It has been found that the conductive material on the vane tends to reduce any electric field present in the cavity, as the electric field will induce currents in the conductive material, and be at least partially dissipated as heat. Preferably the conductive material is arranged to have a specific resistance that best couples the E-fields present in the package to the conductive material.

A further effect of the invention, in addition to the absorption of power in the vane, is a low-order mode cut-off effect, whereby a vane acts, at least partially, to make the cavity in which it is mounted appear to be smaller in size. This can be beneficial due to the nature of field propagation in a cavity. A field propagation pattern within a cavity is termed a mode. The modes that can exist in a cavity are dependent upon the cavity dimensions with respect to the wavelength of propagation of the radiation within the cavity, with the cavity size putting an upper bound on the wavelength that can be maintained in a mode. Thus, a vane applied to a package according to the current invention can make the cavity within the package appear smaller than it is as far as radiation within the cavity is concerned, and so prevent a mode from propagating within the cavity. If this mode is the only one that could otherwise exist, due to the cavity dimensions and wavelength of operation, then the total radiated energy within the cavity will be significantly reduced.

The vane itself is preferably planar, although it may take other forms. In particular, it may be of a shape to match in some way that of the cavity into which it impinges. The vane is preferably positioned on an inner surface of the package such that the plane of the conductive surface of the vane is substantially normal to the package surface on which the vane is mounted. The vane will typically comprise a sheet consisting of one or more materials, which is attached to or otherwise forms part of a package by a connection to an inner surface of the package along an edge of the sheet.

The vane may be formed from any suitable material. In particular, the vane may be made from a material that is itself conductive, but is preferably made

from a dielectric substrate having a major surface onto which is formed a conductive layer. Such a conductive layer may be applied to part or all of the substrate. The substrate is preferably alumina, but quartz, plastic, cardboard and glass are also suitable, amongst others. The conductive material may be nichrome, or a carbon based material such as carbon film, or any other suitable material.

The vane is preferably positioned on a easily removable portion of the package, such as a lid of the cavity. This allows the vane to be conveniently inserted into the cavity volume by fitting or otherwise positioning the lid or other removable portion onto the package. This allows for convenient modification or replacement of the vane so that optimum results can be achieved for differing electric field distributions within the package.

The vane may be formed so as to be an integral part of the package, and so in part comprise the same material that makes up the package, or may be mounted or attached to the package as a separate process. The vane is preferably mounted such that it is in electrical connection with the surface to which it is mounted. If the vane is of a type manufactured separately to that of the package it may be mounted to the package using any suitable means, such as by epoxy, which is preferably conductive, or by using a friction fit into a slot in the package, although any other suitable means may be employed.

The resistance properties of the conductive material may be chosen based upon calculated or estimated impedance values for specific package characteristics. Such calculation or estimation may be done analytically or numerically, and is preferably performed using a computer modelling tool, but may alternatively be performed using a trial and error approach.

More than one vane may be employed within a single cavity. This may be so particularly when the cavity is large relative to the wavelength of operation, or where estimated or calculated field conditions within the cavity indicate that the use of more than one vane may be more effective at attenuating radiation

within the cavity. This will also aid the selective attenuation of specific radiated modes within the cavity.

The or each vane is preferably mounted within the cavity such that a major surface of the or each vane is parallel to an inner surface of the cavity other than the surface upon which the vane is positioned.

The package may be made from any suitable material, such as a milled metallic material. It may also be made from a non-conductive material, wherein preferably the inside surfaces of the package comprise an electrically conductive layer. Such a conductive layer applied to the inside surface of the package is likely to have different conductive properties to that of the conductive layer on the vane.

According to a second aspect of the current invention there is provided a vane for suppressing cavity mode radiation and suitable for mounting within a package for a high frequency electrical circuit, the vane comprising at least in part a layer of conductive material.

The vane preferably comprises a substrate on which is mounted a conductive layer as detailed above.

The vane is preferably mounted to an inner surface of the package along an edge of the vane.

According to a third aspect of the current invention there is provided a high frequency electrical circuit mounted within a cavity in a package, wherein the cavity has an inner surface on which is positioned a vane, the vane comprising at least in part a layer of conductive material.

The vane is a vane as described in relation to other aspects of the invention above.

According to a third aspect of the current invention there is provided a method of manufacturing a package for a high frequency electrical circuit, comprising positioning a vane on an inner surface of the package, the vane comprising at least in part a layer of conductive material.

The invention will now be described in more detail, by way of example only, with reference to the following Figures, of which

Figure 1 diagrammatically illustrates an amplifier packaged in a cavity in a known manner.

Figure 2 diagrammatically illustrates a first embodiment of the current invention, with a single vane mounted on an electric circuit package lid;

Figure 3 diagrammatically illustrates a sectional view of an electric circuit package with lid fitted, according to the current invention;

Figure 4 diagrammatically illustrates a representation of an electric circuit package with a single vane as used for computer modelling experiments;

Figure 5 shows a graph of simulated power absorption properties of a single vane mounted in a package;

Figure 6 diagrammatically illustrates a representation of an electric circuit package with two vanes as used for computer modelling experiments;

Figure 7 shows a graph of simulated power absorption properties of a package incorporating two vanes;

Figure 8 shows a graph comparing measured and modelled power absorption of a single vane with frequency.

Figure 9 shows a graph comparing measured and modelled forward transmission (S_{21}) of a single vane with frequency.

Figure 10 shows a graph comparing measured and modelled input reflection (S_{11}) of a single vane with frequency.

Figure 11 diagrammatically illustrates a simulated package incorporating electrical circuitry and plots of the transmission and reflectance at ports of the package, the package having no attenuating means.

Figure 12 diagrammatically illustrates the same package and transmission and reflectance plots as that shown in Figure 11, but this time incorporating attenuating vanes according to the present invention.

Packages used to hold high frequency circuits are often made from aluminium blocks, with cavities milled into the block made to contain the circuits. Figure 1 shows a cutaway side view of such a package. An aluminium block 1 contains a cavity 2 into which a substrate 3 is mounted that itself has mounted thereon high frequency electrical components 4, that together form an electric circuit. Holes 5a, 5b in the block 1 are provided for signal entry and exit, and for other purposes if necessary, such as power supply connections. A lid 6 made from aluminium sheet is shown detached from the block 1 for clarity but would, of course, be fixed down to the block 1 when the circuit 3, 4 is operational.

In operation, by the nature of electrical circuits, electromagnetic radiation 7 will be radiated from the circuits 3, 4 themselves into the cavity 2. This radiation can couple into a cavity mode, and thence to other parts of the circuit to another part, and so cause undesirable circuit behaviour. A known method of suppressing such radiation 7 is to attach to a part or all of the underside of the lid 6 a radiation absorbing material (RAM) 8. The RAM 8 attenuates the level of reflection of the radiation 7 from the lid 6, and so reduces the energy available to be coupled back into the circuits 3, 4. However, as the frequency

of operation increases this method becomes less effective. The attenuation is not perfect, and losses in the RAM tend to decrease with frequency, and the impedance presented may not provide the optimal conditions for attenuation.

Figure 2 shows a first embodiment of the current invention. Here, a lid 9 is shown that has mounted upon it a vane 10. The vane 10 is fixed by means of conductive epoxy into a slot at edge 11. The vane 10 is made from alumina, and is coated with a conductive film of nichrome. The lid 9 would, in practice, be mounted onto an aluminium block (not shown in this figure) such that the vane 10 is within a cavity formed within the block.

Figure 3 shows a lid such as that shown in Figure 2 mounted on a package. Lid 9 with vane 10 attached thereto is positioned on top of a block 1 that is similar to that shown in Figure 1. In practice, the cavity 2 is likely to be relatively shallow such the bottom of the vane 10 is close to the electrical circuits 4 – the Figure is not to scale. The vane 10 will generally be positioned within the cavity 2 so as to maximise energy absorption from the cavity. This position can often be found by modelling the physical characteristics of a cavity using an electromagnetic simulation software package.

Embodiments of the current invention and cavities to which they may be applied have been simulated using the software package HFSS®. This is a simulation package written by Ansoft, and uses finite element techniques to calculate and graphically display basic electromagnetic field quantities. This particular simulation package is not intended to take into account elements having gain, and so a plain cavity having rectangular cross section and having no sources within it was used as the reference. Figure 4 shows this cavity 12, with a vane 13 mounted centrally to an upper surface of the cavity. Dotted sections indicate waveguide ports 14, 15 that facilitate the simulation of the coupling of energy into and out from the cavity 12. The simulation setup allowed many parameters to be varied, and the effects measured. Parameters varies were vane substrate material and thickness, the conductivity and thickness (together defining the sheet resistance) of a conductive film applied to the substrate, and the frequency of operation.

Vane substrate dielectric constants used in the simulation have taken the values shown in table 1:

ε_r	Simulating material:
1	No substrate
3	Quartz
10	Alumina

Table 1

An important measure is the power absorbed by the vane of energy transmitted between the ports 14, 15. It has been found that the various dielectric constants used in the simulation had only a minor effect upon the power absorption of the vane The higher dielectrics were found to increase the absorption slightly, which may be expected due to the additional field concentration that would result in the vane substrate.

It was also found that the change in power absorption with input frequency was also not large. Measured over the range 70-90 GHz the power absorption varied from approximately 65% to approximately 70% at the best coating conductivity simulated. The primary reason for this variation with frequency is that the waveguide impedance is frequency dependent.

The sheet resistance of the conductive film on the substrate has been found to have a much stronger effect on the power absorption properties of the vane. EM Radiation radiating within a cavity will establish one or more modes of propagation depending upon the dimensions of the cavity in relation to the wavelength of the propagating radiation, and also the geometry of the excitation. Some or all of these modes may be evanescent modes. The impedance, given by the ratio of the electric and magnetic fields, at a particular point in the cavity will vary according to the modes established in the cavity.

The maximum absorption of power within the vane will take place when the resistance of the vane matches the wave impedance. For a particular rectangular cavity (with no vane present) the magnitude of the wave impedances of some low-order transverse electric (TE) modes – designated as TE_{nm} – have been calculated at a frequency of 80GHz, and are presented in Table 2.

TE_{nm}	n=0	n=1	n=2
m=0	-	427	1083
m=1	273	259	226
m=2	116	114	111
m=3	75	75	74

Table 2

Thus the vane should ideally be made to match with the appropriate modes within the cavity. However, insertion of objects into a cavity can change the modes supported in the cavity – modes which could be either propagating or evanescent – that takes place. This will apply to the vane or vanes of the current invention also. This should be considered when estimating the sheet resistance and thickness of the film to be used to coat the vane substrate.

Figure 5 is a graph showing the effects of sheet resistance on power absorbed for the cavity of Figure 3. The graph shows the percentage power absorbed against the sheet resistance of a conductive film applied to a vane substrate 0.01" (0.254mm) thick with ε_r=10, with a signal frequency of 80 GHz. Four traces are shown, these representing film thicknesses of 3μm, 1μm, 0.5μm and 0.1μm. In all cases the sheet resistance corresponding to the greatest power absorption is between approximately 100Ω/square and 200Ω/square, closely matching the m=2 modes of Table 2. The 3μm film coating is found to be the most efficient absorber.

Figure 6 shows an embodiment of the current invention employing two vanes 16, 17, mounted within a cavity 18 such that they are equidistant from each

other and from the sidewalls 19 of the cavity 18. As there are now two objects in the cavity, this will change the dominant modes within it, and so will also change the impedances of the EM radiation making up the modes.

A graph of the power absorbed by both vanes 16, 17 against sheet resistance therefore shows, in Figure 7, a difference in the sheet resistance at which maximum power is absorbed, and the value of the maximum absorption itself as compared to the single vane case of Figure 5. Sheet resistances of around 50Ω-90Ω/square have been found to be most absorbent consistent with the m=3 modes of Table 2.

The sheet resistance of a film coating used on a vane will, as shown above, affect the power absorption of the vane in a cavity. The film coating can be adapted to enhance the low order mode cut-off effects of the vane, whilst also maintaining an impedance match to cavity modes.

The effectiveness of the current invention is thought to be due to both the impedance matching techniques discussed above, and also a low-order cutoff effect. The skin depth of a material is inversely proportional to the square root of conductivity and operating frequency. The sheet resistance is inversely proportional to conductivity. Hence, by choosing a low conductivity film, a vane can be made which has the desired effective sheet resistance for absorption at the operating frequency. At the same time, if the film is sufficiently thick with respect to the skin depth, this will make the vane act as a metal wall raising the minimum frequency for propagation. If a vane with these properties is placed in the centre of the waveguide it will force the propagating wave into a TE_{20} mode as it passes the vane. If the operating frequency is too low to support the TE_{20} mode it will not propagate. Therefore the vane will act as both an attenuator at high frequencies and as a high pass filter.

Thus the use of a vane having a thicker conductive film made from a material having a lower conductivity will tend to have the properties of a metal wall, so

improving the low order mode cut-off, whilst maintaining an impedance match for any modes that are still generated.

It has been found that the farther the vane intrudes into the package cavity the better the vane is at attenuating the radiation.

The calculations presented above have all been generated using simulations on a computer system. Quantitative measured results have also been obtained on a cavity of rectangular cross section 2.4mm x 1.3mm, and these results compared to computer simulations of the same cavity. For ease of measurement this cavity had a port at each end allowing accurate measurements to be made. A vane comprising a sheet of alumina of thickness 0.254mm (0.01") onto which has been coated a nichrome film of thickness 90nm was placed in the cavity and measurements made indicative of the absorption and reflection characteristics of the cavity over the frequency range 70GHz to 110GHz.

Figure 8 shows the results for power absorbed by the vane, and also the results of a computer model of the cavity. The results track each other reasonably well, particularly towards the higher frequency end of the graph.

Figure 9 shows a plot of the parameter S_{21}, or the forward transmission coefficient, for both the modelled and measured cavities. Again, a reasonable agreement is found between the two, especially when it is considered that the parameters are plotted on a logarithmic (dB) scale.

Figure 10 shows a plot of the parameter S_{11}, or the input reflection coefficient, for both the modelled and measured cavities. Again, a reasonable degree of similarity is found between the two, bearing in mind that the parameters are plotted on a logarithmic (dB) scale.

The match between the measured and simulated results indicates the validity of the simulations done on an enclosed cavity as presented in relation to Figures 2 to 7.

Figures 11 and 12 shows quantitatively the improvement that results from using the invention as described herein on a package incorporating electrical components operating at a high frequency. Figure 11a shows a model of a package 100 which contains two ports, 101, 102. Each port 101, 102 has an electrical circuit comprising a microstrip line 103, 103' terminated with a resistance 104 104' and a bias tee matching stub 105, 105' A gap exists between the circuits relating to each port 101, 102, such that there is no DC connection between the circuits. The package dimensions are 4mm x 3mm

Figure 11b shows the modelled electrical characteristics of the cavity of Figure 11a. The trace identified with square markers represents the transmission (S_{21}) coefficient between the two ports 101, 102. It can be seen that this peaks at around 60 GHz, where there is only a 5dB loss between the ports. This transmission is primarily due to cavity mode coupling between the circuits connected to each port 101, 102. The other two traces, marked by circles and vertical dashes, represent S_{11} and S_{22} respectively, and these are seen to have a resonance at the same frequency.

This therefore shows the problem that exists due to cavity mode coupling of electrical circuits. Without the cavity effects there would be very little transmission of energy between the ports.

Figure 12a shows the same cavity and circuitry as that shown in Figure 11a, but this time utilising two vanes 106, 107 according to the present invention on the upper surface of the cavity 100. The vanes were modelled as 100μm thick quartz substrates, with a 70Ω/square conductive coating on a surface of each one.

Figure 12b shows the simulated results for the cavity of Figure 12a. Again, the trace identified with square markers represents the transmission (S_{21}) coefficient between the two ports 101, 102. It can be seen here that by

incorporating the vanes 106 107 into the cavity 100 the transmission between the ports 101, 102 has dropped to almost –50dB. The resonances in the reflectance parameters S_{11} and S_{22} have also been eliminated.

Note that in this specification the terms "electrical" and "electronic", and terms derived from these shall be regarded as synonymous.

The skilled person will be aware that other embodiments within the scope of the invention may be envisaged, and thus the invention should not be limited to the embodiments as herein described.

Claims

1. A package for a high frequency electrical circuit comprising a cavity formed within a material for containment of the electrical circuit, characterised in that the package contains at least one vane positioned on an inner surface of the package such that the or each vane substantially extends into the cavity, the or each vane at least partly comprising a conductive material.

2. A package as claimed in claim 1 wherein the or each vane is substantially planar.

3. A package as claimed in claim 1 or claim 2 wherein the or each vane comprises a layered structure with a first layer comprising a substrate and a second layer comprising a conductive material.

4. A package as claimed in any of claims 1 to 3 wherein at least one region of the conductive material is arranged to have a specific resistance substantially similar to that of a predicted electromagnetic field that will be present when the cavity is in use.

5. A package as claimed in any of the above claims wherein the vane has conductivity properties different to that of other parts of the cavity.

6. A package as claimed in any of the above claims wherein the package is designed to house circuitry operative in the millimetre wave region.

7. A package as claimed in any of claims 1 to 6 wherein the or each vane is mounted on a removable portion of the package.

8. A package as claimed in any of claims 1 to 7 wherein the or each vane is mounted such that the vane or a major surface thereof is substantially normal to the surface on which the vane is mounted.

9. A package as claimed in any of claims 1 to 8 wherein the or each vane is mounted in a substantially symmetric fashion within the cavity in relation to a pair of opposing walls of the package.

10. A package as claimed in any of the above claims wherein the conductive material comprises nichrome.

11. A package as claimed in any of the above claims wherein the conductive material comprises carbon.

12. A package as claimed in claim 3 wherein the substrate comprises alumina.

13. A vane for suppressing cavity mode radiation and suitable for mounting within a package for a high frequency electrical circuit, the vane comprising at least in part a layer of conductive material.

14. A vane as claimed in claim 13 wherein the vane comprises a substrate upon which is arranged a conductive layer.

15. A vane as claimed in claim 14 wherein the vane is mounted to an inner surface of the package by means of being affixed substantially along, an edge of the vane.

16. A high frequency electrical circuit mounted within a cavity in a package, wherein the cavity has an inner surface on which is positioned a vane, the vane comprising at least in part a layer of conductive material.

17. A method of manufacturing a package for a high frequency electrical circuit, comprising positioning a vane on an inner surface of the package, the vane comprising at least in part a layer of conductive material.

Improvements Relating to Electronic Circuit Packages

Abstract

This invention relates to electronic circuit packages designed to hold high frequency circuits, particularly, but not exclusively, operating at the millimetre wave band. The invention provides a package incorporating a cavity in a material for containment of the circuits, wherein the package further incorporates at least one vane mounted on an inner surface extending into the cavity, the vane comprising a conductive material. The vane according to the present invention will tend to attenuate electromagnetic radiation present within the cavity, and so help to prevent undesired coupling from one point to another within the cavity. The conductivity of the conductive material is preferably arranged to match the impedance of the radiation mode estimated or computed to be present within the cavity. The vane is preferably mounted on a removable portion of the package, such as a lid.

(Figure 2)

Figure 1 (Prior Art)

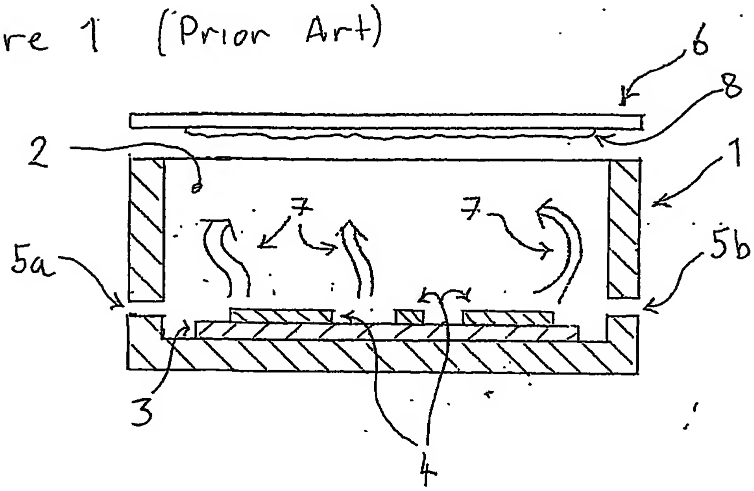


Figure 2

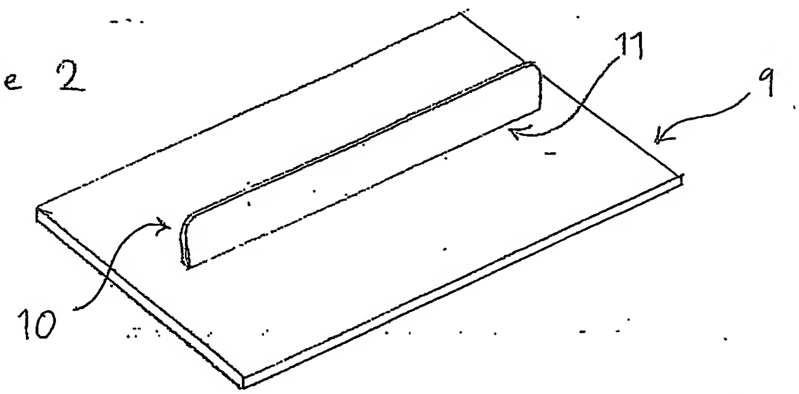


Figure 3

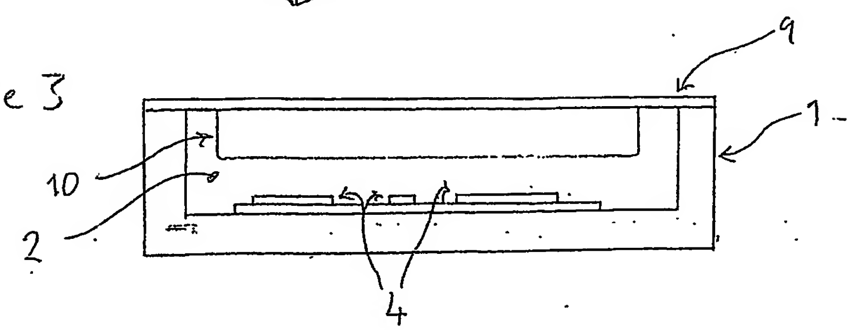
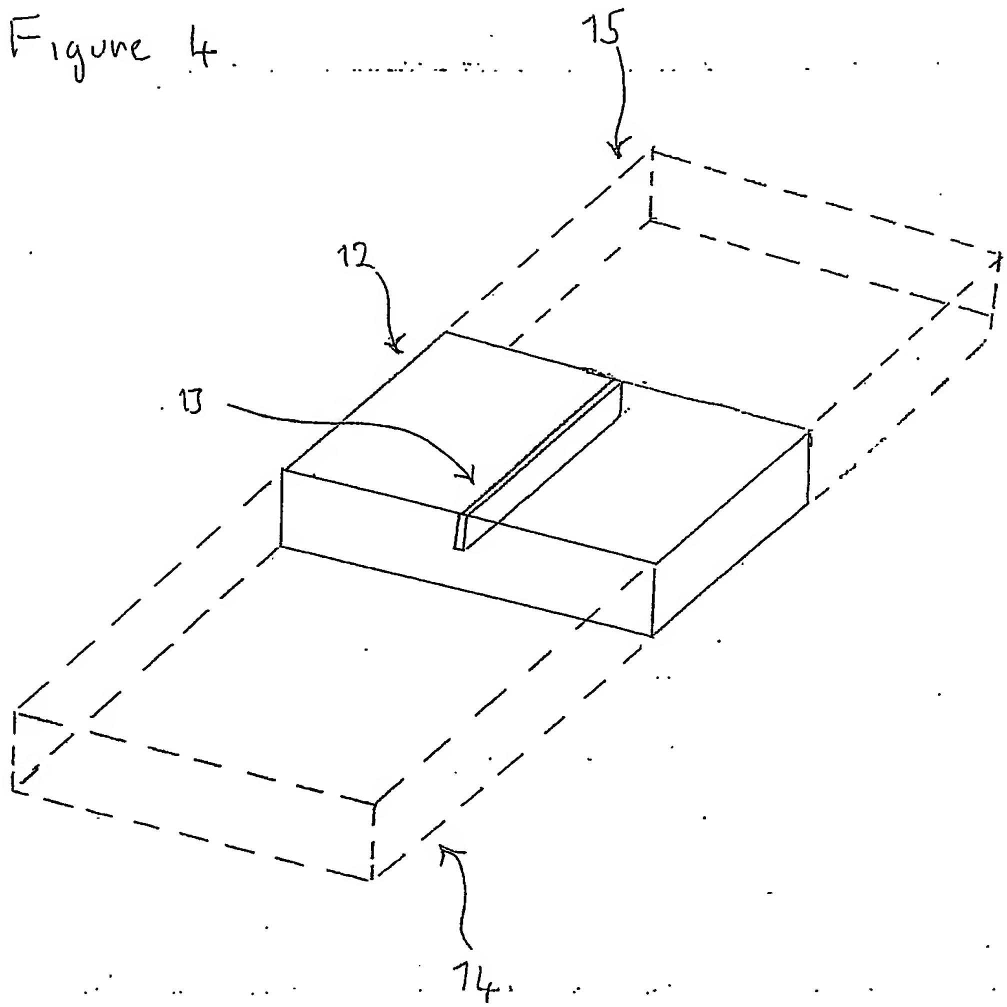


Figure 4



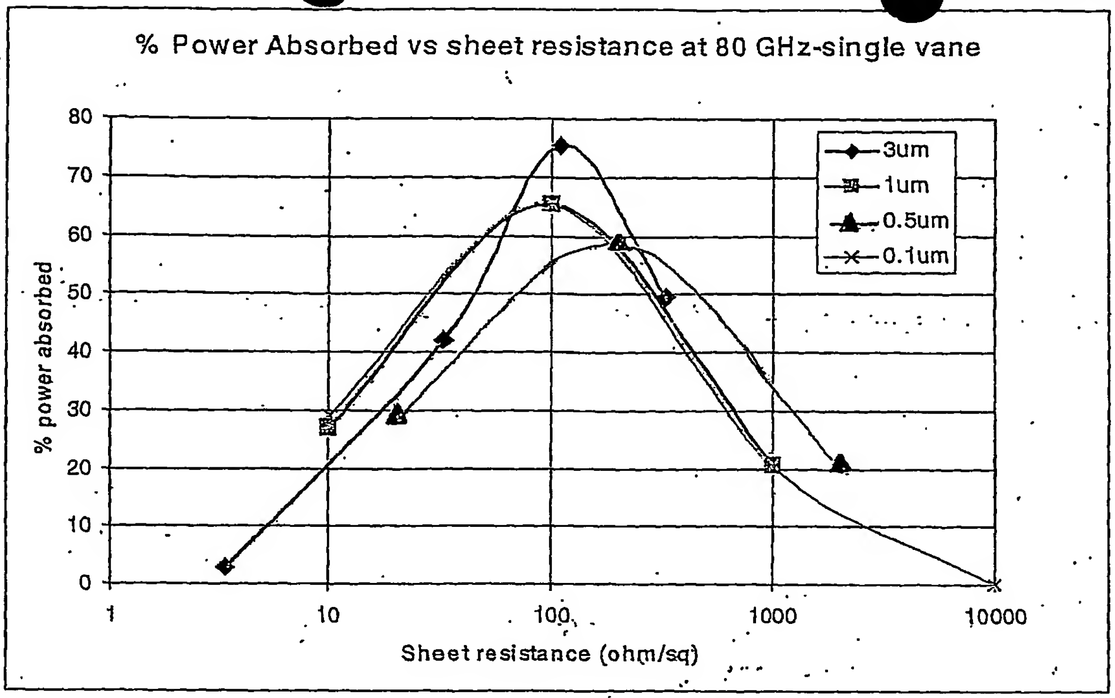
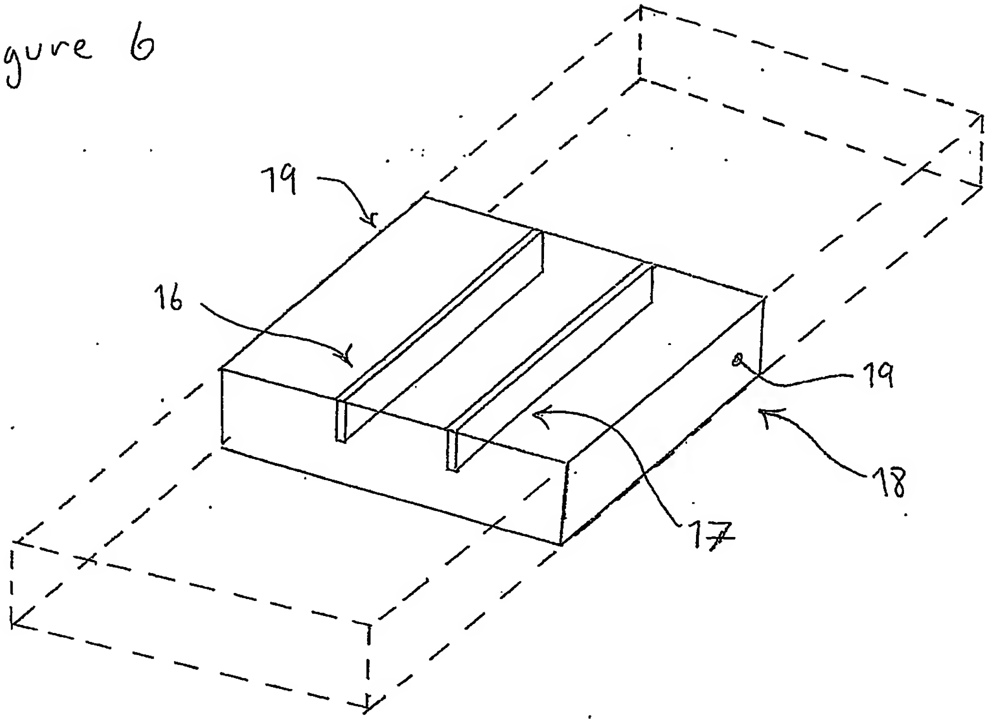

% Power Absorbed vs sheet resistance at 80 GHz-single vane
% power absorbed
80
70
60
50
40
30
20
10
0
1
10
100
1000
10000
Sheet resistance (ohm/sq)
3um
1um
0.5um
0.1um

Figure 5

Figure 6



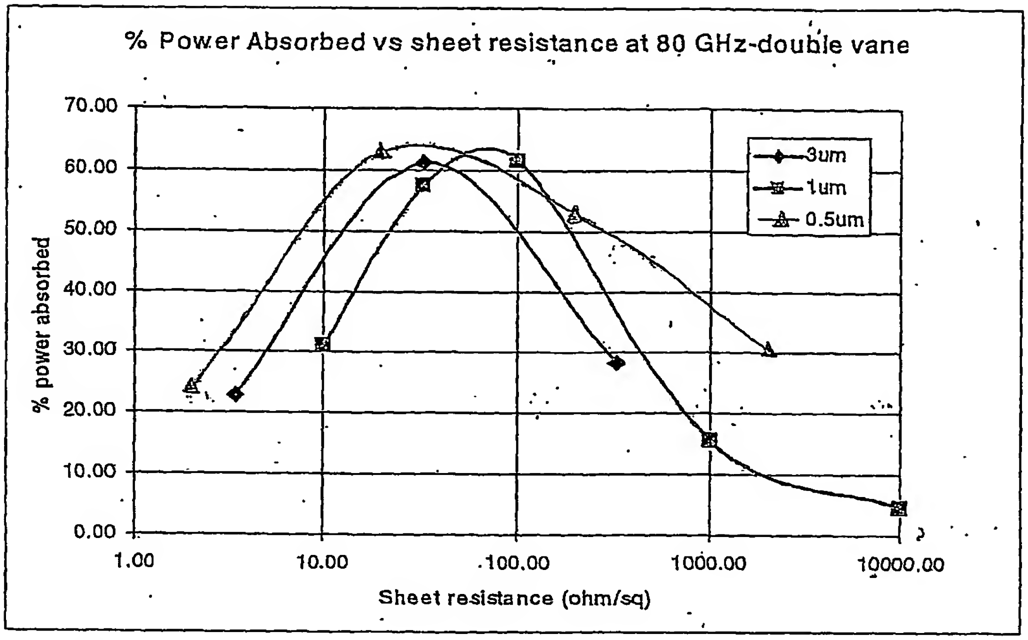

% Power Absorbed vs sheet resistance at 80 GHz-double vane
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
% power absorbed
1.00
10.00
100.00
1000.00
10000.00
Sheet resistance (ohm/sq)
3um
1um
0.5um

Figure 7

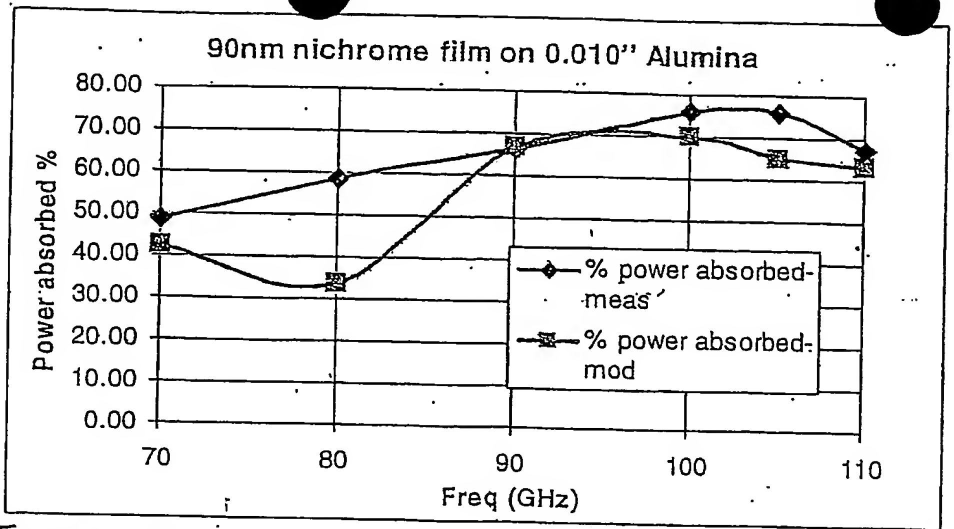


Figure 8

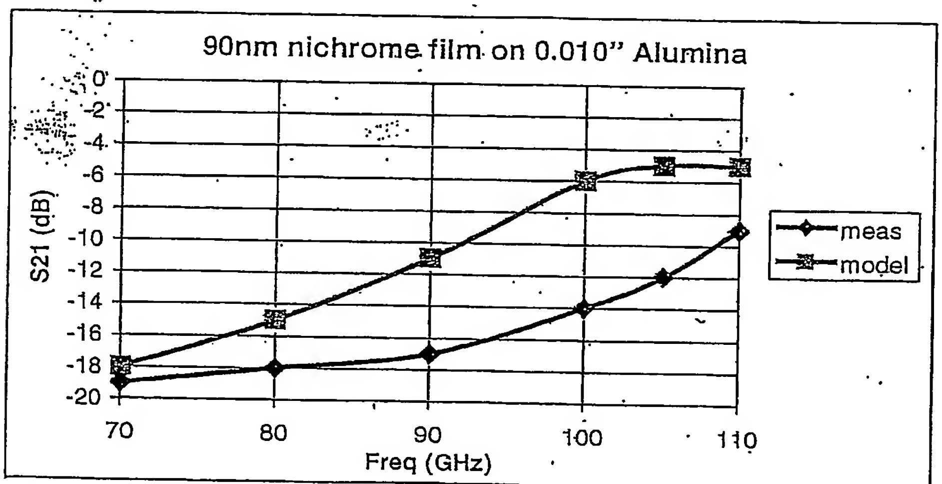


Figure 9

Figure 10

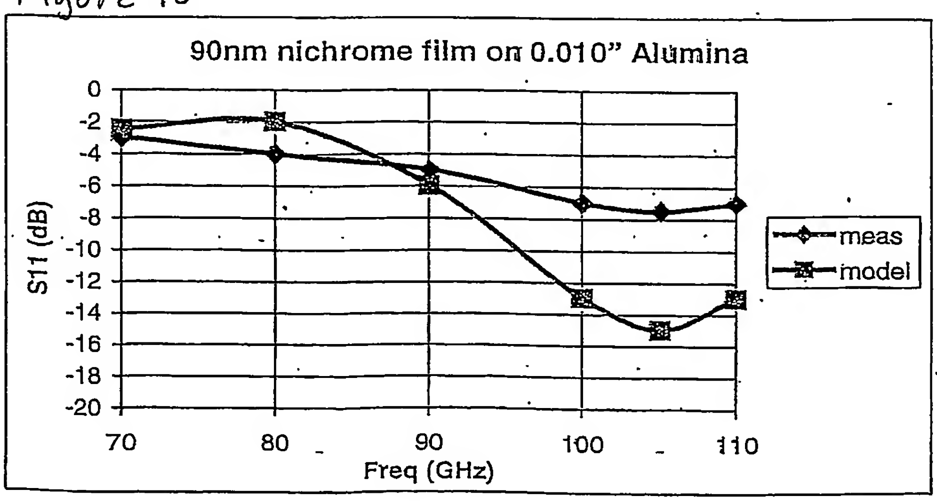
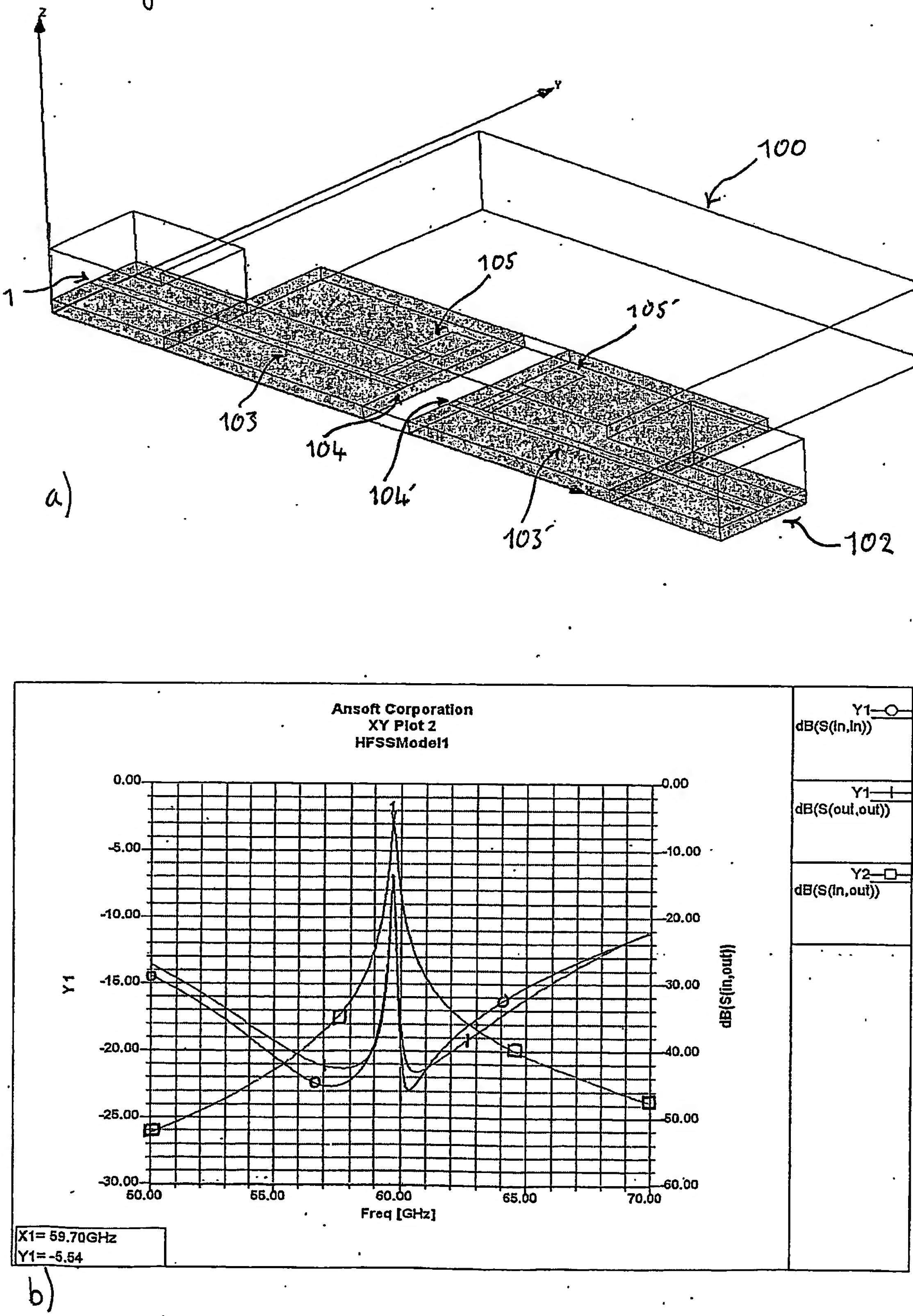
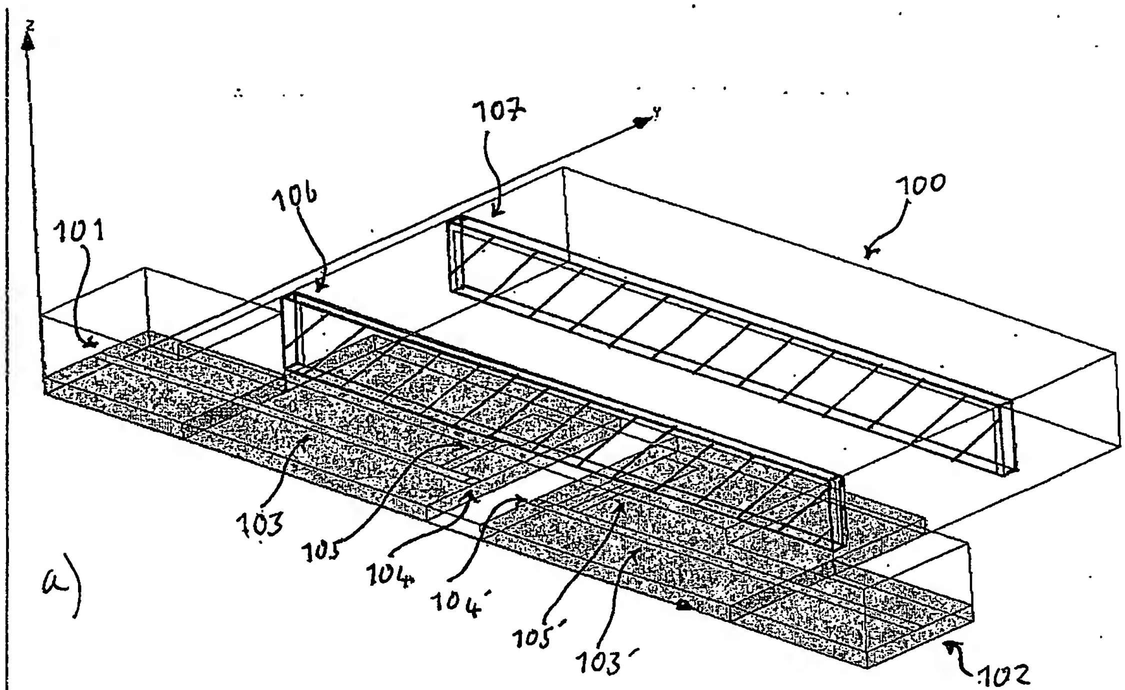


Figure 11



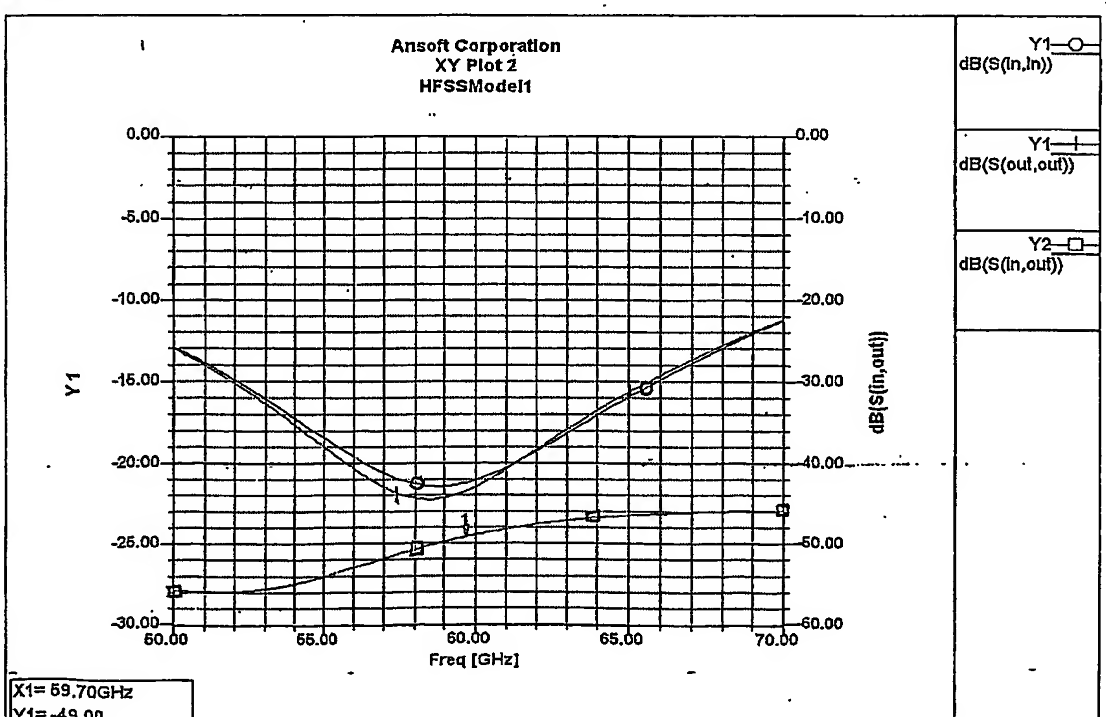
Z
Y
100
101
105
105'
103
104
104'
103'
102
a)
Ansoft Corporation
XY Plot 2
HFSSModel1
Y1
dB(S(in,in))
Y1
dB(S(out,out))
Y2
dB(S(in,out))
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
0.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
50.00
55.00
60.00
65.00
70.00
Freq [GHz]
dB(S(in,out))
X1= 59.70GHz
Y1= -5.54
b)

Figure 12



107
106
101
100
103
105
104
104´
105´
103´
102

a)



Ansoft Corporation
XY Plot 2
HFSSModel1
Y1
dB(S(in,in))
Y1
dB(S(out,out))
Y2
dB(S(in,out))
0.00
-5.00
-10.00
-15.00
-20.00
-25.00
-30.00
-10.00
-20.00
-30.00
-40.00
-50.00
-60.00
dB(S(in,out))
60.00
55.00
60.00
65.00
70.00
Freq [GHz]
X1= 59.70GHz
Y1= -49.00

b)

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